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VIBRATION REDUCTION OF FLEXIBLE BEAMS USING SHAPE MEMORY ALLOYS

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ABSTRACT

Damage to machinery due to large vibration amplitudes at or near critical speeds can be avoided by the use of external dampers, which help in keeping vibration amplitudes under tolerable limits by dissipating a part of the undesirable vibration energy generated. Of several mechanisms by which external dampers could be provided, application of shape memory alloys (SMA) for the purpose has recently started gaining attention from researchers. As such, an attempt has been made to explore the possibility of applying SMA for vibration attenuation. Systematic experiments have been carried out in order to study the feasibility of using an SMA strip to reduce the vibration of a typical structural element like a cantilever beam. The performance of the SMA strip in this context has been defined qualitatively in the form of decay curves and quantitatively in terms of the damping ratio. The study has very clearly indicated that an SMA strip is a potential candidate when applied as a layered damper in flexible structures. The study also indicates that the application of an SMA strip needs to be optimized for better performance and the possibility of realizing active vibration control.

KEY WORDS: Active Vibration Control, Beam, Transient Vibration, SMA Damping

1. INTRODUCTION

Increased demand for optimum mechanical design of machinery components has led to the design of structures, especially aerospace structures, with enhanced damping capabilities. The structural dampers may be passive or active in nature. It has been observed from literature that out of several vibration attenuation techniques for machinery structures, the layer damping technique has assumed importance because of its simplicity. The recent literature reviewed related to the dissipation of vibrational energy through a layer damping technique (both unconstrained and constrained) reveals that mainly visco-elastic materials or piezo-electric actuators have been used alloys as a layered vibration attenuator. Baz et al. [6] have studied the active vibration control of flexible beams using SMA wires (NiTinol). A mathematical model has been developed incorporating the thermal and dynamical characteristics of SMA wires and an FE model of the beam to study the active vibration control. The performance of the vibration controller has been tested experimentally.

A theoretical work has been carried out by Chen et al. [7] to study the active vibration control of elastic beams by means of shape memory alloy layers. The mathematical model of a flexible beam covered with SMA layers is presented. The SMA layers are used as actuators, which are capable of changing their elastic modulus and recovery stress, thus changing the natural frequency of the vibrating beam.

As very little data is available regarding the experimental and quantitative analysis of structural vibration reduction using an SMA layer as a damping medium, an attempt has been made here to obtain qualitative/quantitative experimental results considering several relevant parameters.

2 METHODOLOGY, TEST RIG AND INSTRUMENTATION

The damper performance study here was restricted to obtaining the damping levels qualitatively by way of realizing the decay curves of transient vibration and quantitatively in terms of the damping ratio calculated by the logarithmic decrement method from transient decay curves. As such free vibration tests were conducted on a simple cantilever structure. A simple rig consisting of a cantilever beam schematically shown in figure 1 was fabricated and instrumented for the purpose.

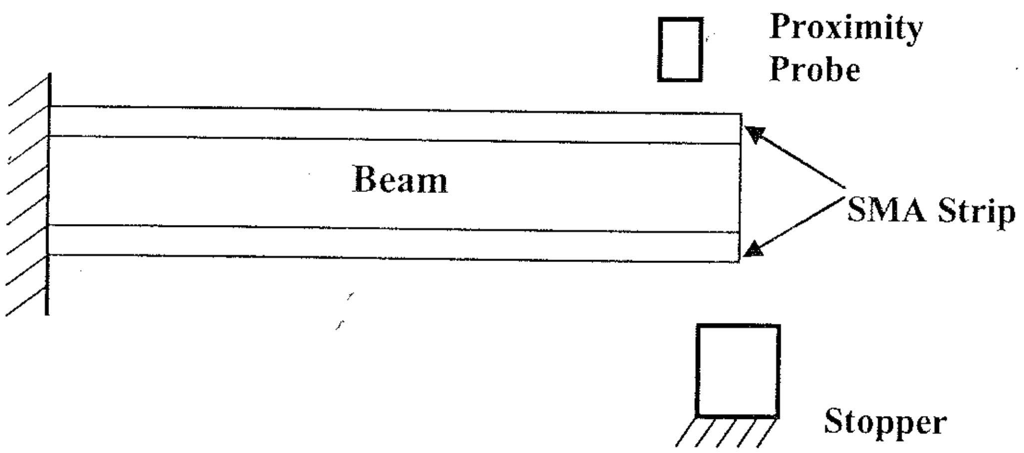

Fig. 1 Schematic of the test rig

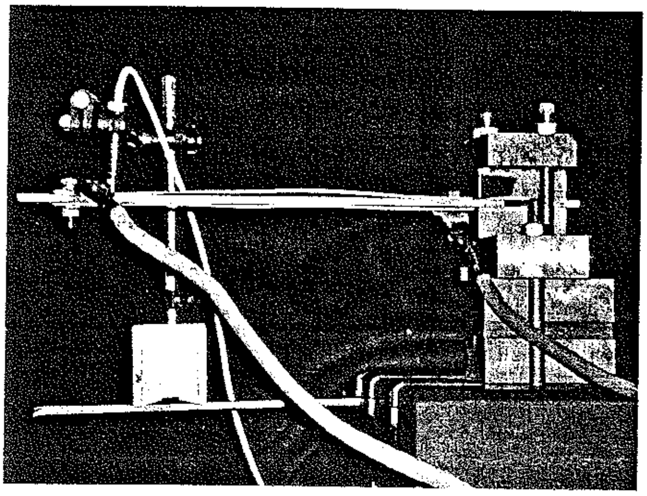

Fig. 2 Photograph of the Test Rig

The instrumentation included capturing of the amplitude signals resulting out of beam vibration as a result of initial disturbance using a non-contact proximity probe and conventional data acquisition system. The photograph of the rig is shown in figure 2. A detailed experimental study was conducted on different fixing conditions of the SMA strip on the elastic beam in order to bring out the effect of fixing conditions on the damping contribution. The experimental study was systematic in nature. The design of the rig facilitates realizing different boundary conditions for the free vibration in different test

3. TRAINING OF THE SMA STRIP

The essential requirement during the application of SMA is the training that needs to be provided. For the application in question, it was planned to train the SMA strip to a particular shape (in this case deformed to a bowed shape), before layering it on the beam. Initially the planar strip was heated above the austenitic transformation temperature and then deformed to the bow shape up to a desired level. The SMA strip was heated by resistive heating method. The deformed strip was then cooled to room temperature (martensite phase) and the deformation removed. Subsequent heating of the strip above austenitic transformation temperature should regain the bent shape of the strip due to memory effect if the training is complete. If not, this process is repeated till the desired bending upon heating is achieved. A typical SMA strip measuring 2 mm thick and 25 mm wide with a length equal to the beam under question was thus trained for different bow shapes. The training scheme is schematically shown in figure 3.

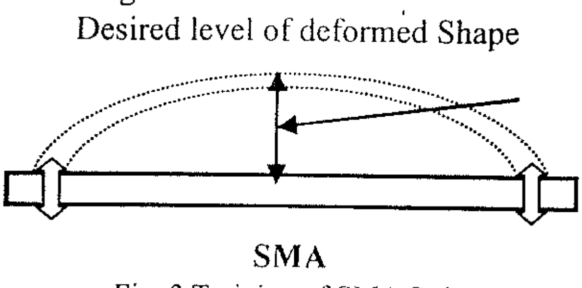

Fig. 3 Training of SMA Strip

4. RESULTS AND DISCUSSION

The detailed experimental study included obtaining the decay curves for various configurations of SMA layered damping in order to study their effect on the damping contribution. Different cases on which the study was conducted are discussed. In order to obtain the effect of the fixing location of the SMA strip on the beam, several configurations have been studied as shown in figure 4.

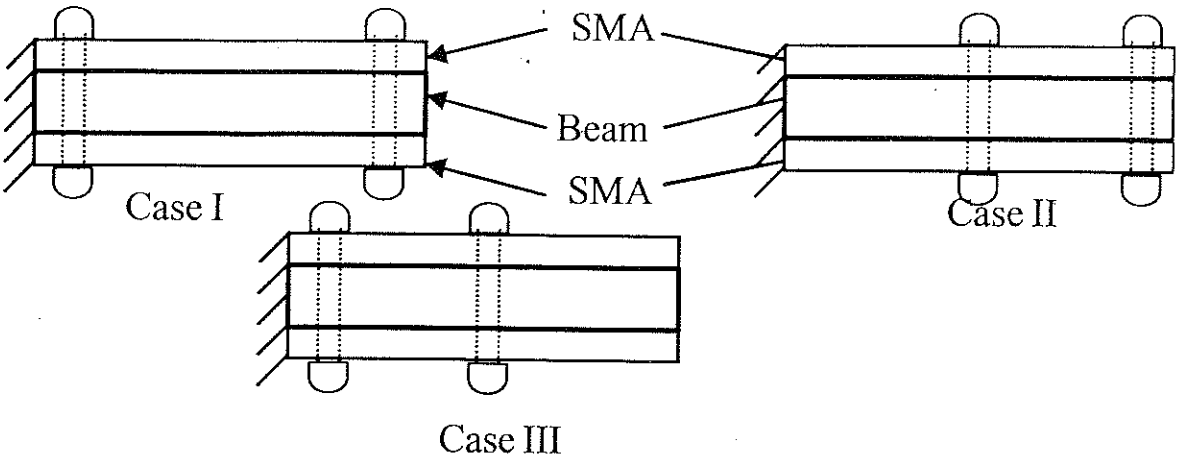

Fig. 4 Different configurations of attaching the SMA strip on the beam.

The three configurations of fixing the SMA layer included different fixing conditions such as

i) fixed end and free end
ii) fixed end and middle of the beam and
iii) free end and middle of the beam

There are basically two ways how a trained SMA strip could be fixed to the beam. While the first way is to fix the trained SMA layer in such an orientation that the bent shape is convex outward with respect to the cantilever beam, the other is to fix it in the reverse orientation so that SMA strip tries to bend convex towards the cantilever beam (referred henceforth as reversed fixing in this paper). Experiments were conducted to initially identify a relatively better way of fixing the SMA layer (i.e. reversed or not reversed) from damping potential considerations.

It was observed that the orientation of the deformed face of the SMA strip, while fixing it on the beam does marginally affect the vibration attenuation. The effects can be seen from figure 5. The activated SMA strip in reversed condition provides relatively higher vibration reduction. This may be attributed to the fact that at relatively higher strained condition (as in the case of reversed fixing), the SMA strip offers higher level of damping. Hence, the subsequent studies for testing the three different cases of fixing conditions were conducted using the SMA layer fixed in the reversed condition.

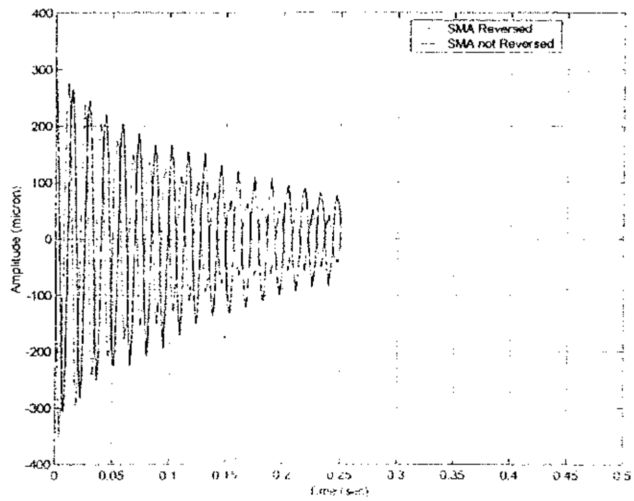

Fig. 5 Beam vibration with heating the SMA

Transient vibrations of the flexible cantilever beam, with SMA strip attached in three different fixing conditions, have been studied experimentally. The beam vibration was recorded for all the three cases (refer figure 4) using a proximity probe fixed close to the free end and plotted in figures 6, 7 and 8 below.

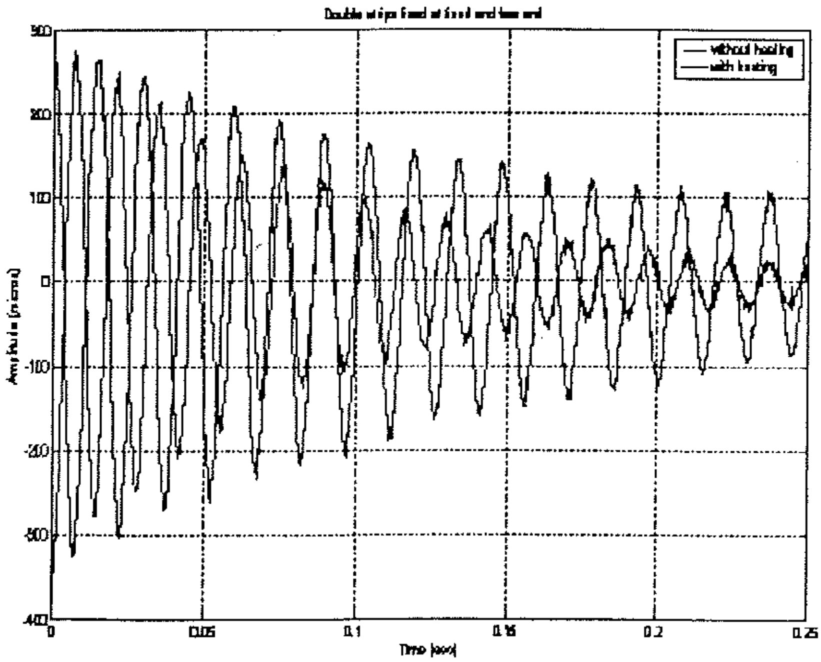

Fig. 6 Flexible Beam Vibration with and without activating the SMA, Case-I

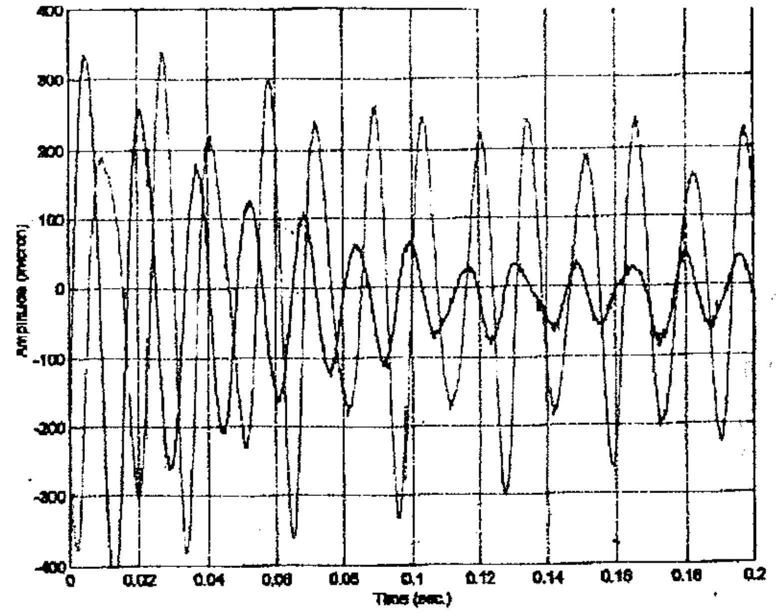

Fig. 7 Flexible Beam Vibration with and without activating the SMA, Case-II

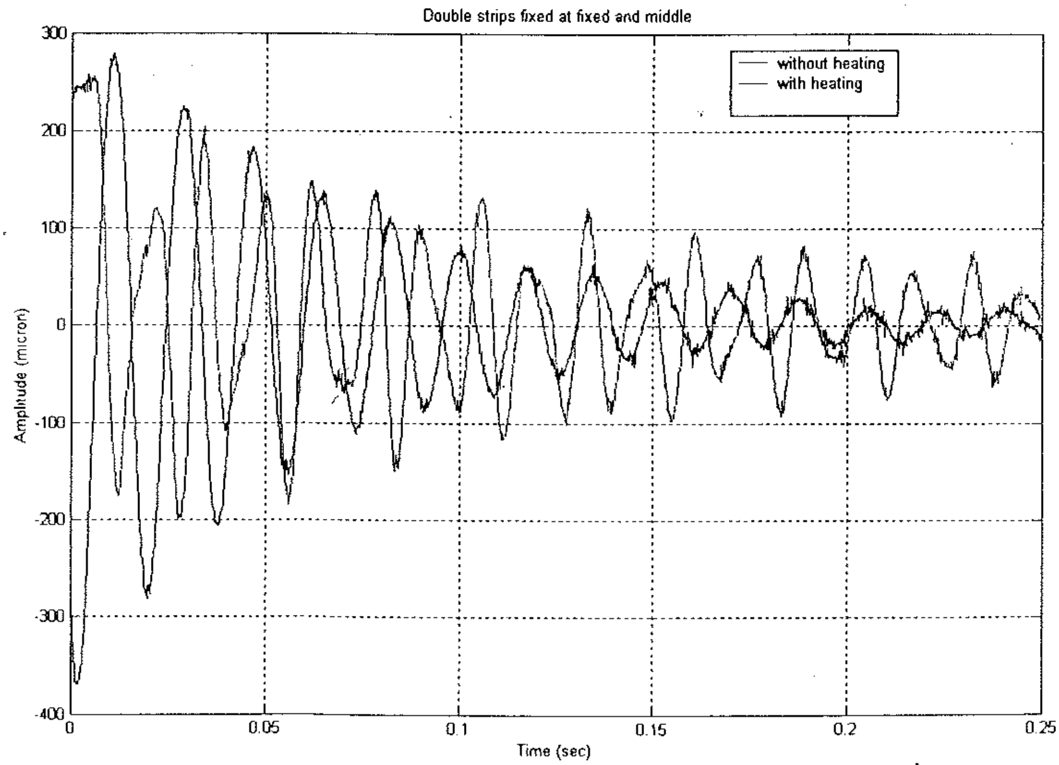

Fig. 8 Flexible Beam Vibration with and without activating the SMA, Case-III

The results are plotted using similar starting amplitude of vibration to facilitate easy comparative study between the activated and non activated SMA cases. It can be seen from the plots that the vibration reduces considerably when the SMA layer is activated by heating it above the austenite transformation temperature (80 ^{0}C in this case) for all the three cases. The degree of attenuation appears to be more in case III, i.e. the SMA bolted at the fixed and middle of the beam, as compared to the other two cases.

The damping ratios calculated following a logarithmic decrement method from the decay curves for all the above cases are given in Table 1. The damping ratio in case III is relatively higher as compared to the other cases. Comparing damping ratios values for reversed and non-reversed orientation of the SMA strip, it can also be concluded that fixing an SMA strip in the reversed orientation gives better performance.

Table 1: Comparison of damping ratios

Configurations	Case I	Case II	Case III
SMA heated	0.0228	0.0323	0.0326
SMA at room temperature	0.0110	0.0118	0.0148

5. CONCLUSIONS

An attempt has been made here to bring out the effectiveness of the layer damping technique using SMA (NiTinol) through experimental studies. It is observed that considerable vibration attenuation takes place when the SMA strip is heated above the austenite transformation temperature. The effects of fixing conditions and orientation of the SMA strip on the vibration reduction have also been studied. It may be concluded that the SMA layer is a potential technique for vibration reduction of structural components.

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